EVALUATING THE PERCEPTION OF DESIGN ERRORS IN THE CONSTRUCTION INDUSTRY

BY

GEORGE NEIL SUTHER, R.A.
LIEUTENANT
CIVIL ENGINEER CORPS
UNITED STATES NAVY

A REPORT PRESENTED TO THE GRADUATE COMMITTEE OF THE DEPARTMENT OF CIVIL ENGINEERING IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF ENGINEERING

UNIVERSITY OF FLORIDA

Summer 1998

This report is dedicated to Beverley and Neil. Thank you for your understanding and support and for those important quiet times. Beverley served as my sounding board, proof reader, cook and chief bottle washer. Neil was my inspiration, always telling me what a good job I was doing. High five buddy!

ACKNOWLEDGEMENTS

The success of this report is not without the assistance and guidance of several people. Many thanks must go to my friend and advisor Dr. Charles (Chic) Glagola for providing interest, expertise and guidance. To my other committee members Dr. Paul Thompson for paving the way through graduate school and Dr. Ralph Ellis for his insight to the contractors view on design errors.

I appreciate the talents of Jennifer Languell, a Ph.D. candidate, who helped calm me when the computer ate my paper. She successfully retrieved my work using that voodoo that she do so well.

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EXECUTIVE SUMMARY

EVALUATION OF THE PERCEPTION OF DESIGN ERRORS IN THE CONSTRUCTION INDUSTRY

The owner, designer and contractor all have different interests in, or uses for the design of a facility. But what they do share is the commitment to complete the project safely and within a given budget and completion time. There are many initiatives being conducted to control the growth of cost and schedule within the construction industry. The major issue is "accuracy of the drawings," or the number of design errors, omissions and ambiguities within the plans and specifications that affect the quality of the facility. Inadequacies in the plans and specifications are the major causes of changes to the contract. So much emphasis is placed on the issue of time and cost that quality takes a back seat. The quality of the project depends on the conformance of the objectives and requirements from the owner. An informative quality management technique will provide an agreement to procedures and definitions among the principle parties for the project. Since design errors have an impact on the outcome of the effectiveness of the contractor's effort on the project, it is essential that all parties determine what the definition of a design error should be. When asked to define design error, not all disciplines in the construction process agree on a common definition. From the basic definition of design and error it can be determined that a design error is a deviation from a drawing or specification. It is the seriousness of this error that must be considered to determine its consequences on the overall outcome of the project. There have been extreme examples of design errors such as the Hyatt Regency walkway and Kemper Arena roof collapse - projects that have wrought disaster after the construction are completed. This paper examines the perception of the definition of design error among the principle parties in the construction industry, the major sources to project changes and the factors that control design and construction. The paper further examines the contributing factors to design errors, steps taken by firms and recommendations to reduce design errors.

I. INTRODUCTION

When asked to define "design error," not all disciplines in the construction process agree on a common definition. Depending on which discipline you address, the owner, the designer or the contractor there will be a common understanding surrounded by varied conclusions, "a mistake." From the basic definitions of "design" and "error" we conclude that a design error is a deviation from a drawing or specification, also including omissions and ambiguities. It is the seriousness of this error that must be considered to determine its consequences on the overall outcome of the project. One of the most important challenges facing management today is controlling the all too frequent cost and schedule overruns that effect the construction industry (Diekmann and Thrush, 1986). One of the major issues to control growth in project costs and time is the reduction of design errors.

Statement of the Problem

Design errors indicate the total design effectiveness of a project. Major design quality problems occur during construction when errors, omissions and ambiguities in plans and specifications become evident (Davis and Ledbetter, 1987). This statement directs that the inadequacies in the plans and specifications are the major causes of changes to the contract. There have been extreme examples of design errors such as the Hyatt Regency walkway and the Kemper Arena roof collapse - projects that have wrought disaster after the construction are completed. These are examples of design errors that escaped the close scrutiny of all parties. One or two major errors that can be corrected with only cost considerations and little effect on the schedule can impact

projects. The projects that really suffer are those with many small errors (design, rework or change of scope) which when finally added up cause major impacts on the cost and schedule growth. Through Davis and Ledbetters research it was determined that "accuracy of the design documents" was the most critical of the criteria used in the initial evaluation of design effectiveness. This accuracy was further described as the concern for the frequency and impact of errors in the specifications and drawings. This is due to the fact that the drawings and specifications are the most "readily identifiable outputs of the design process." It is evermore important that the quality control of designs be addressed during the planning phase and closely monitored during the construction phase.

Objective of the Study

The objective of this research was to collect data, through surveys and interviews, from the principle players in the construction industry to determine their perception of what constitutes a design error. Through this methodology an analysis was conducted to examine some of the major contributing factors to design errors and at what level they affect cost and schedule growth in construction projects. The areas of focus were to determine if the principle parties:

1. agreed on a definition of design error;
2. were interested in the burden of responsibility for errors financially;
3. ranked the factors that control design and construction under a common interest;
4. believe that computer aided drafting has reduced the number of design errors and improved production;
5. could assign a percentage to design errors in relation to all project changes.

II. WHAT IS A DESIGN ERROR

Since design errors have an impact on the outcome of the effectiveness of the contractor's effort on the project, it is essential that all parties determine what the definition should be. It is essential that all the principle parties involved in the project get an up front agreement on the determination of a design error, and how they will be handled when they occur.

Definition of Design

The basic definition of design, according to Webster, is "the making of drawings or plans to plan and fashion the form and structure of an object to have intentions or purposes." The quality of planning and design is one of the primary factors of success in any project endeavor (Chalabi, Beaudin and Salazar, 1987). The design includes every aspect of the facility construction including operation and maintenance. The design incorporates a set of specifications to guide the contractor in developing his means and methods of construction. Figure 2-1 shows the traditional flow diagram of a design/construction method.

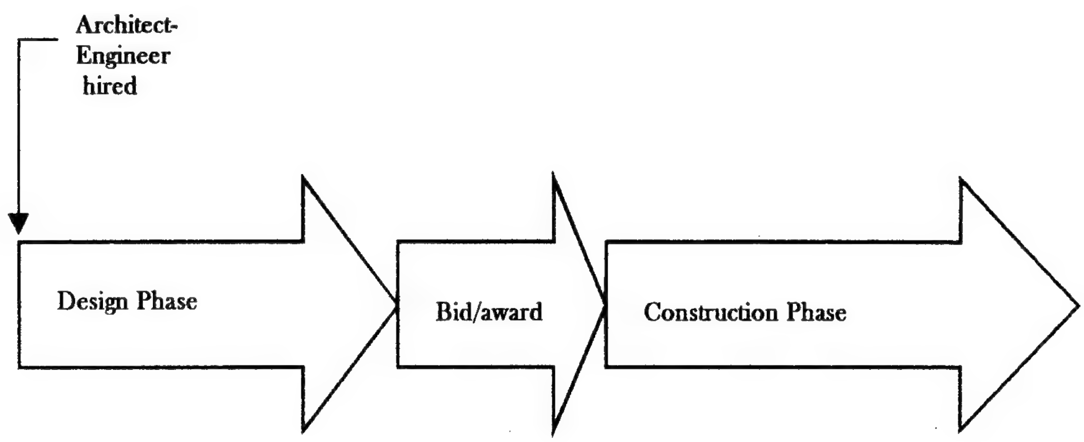


Figure 2-1. Traditional flow diagram of design/construction method. (From GSA System for Construction Management, General Services Administration, Public Buildings Service, Washington, DC, rev. ed., April 1975.)

It is important to note that within the contract, the designer does not warrant that it's design, drawings, specifications and other services will be free from error. Competent designs are subjected to the influences of design inputs from numerous sources, which multiplies the possibility of error.

Definition of Error

An error is defined, according to Webster, as "a deviation from accuracy or correctness; a mistake, as in action or procedure; an inaccuracy, as in speaking or writing." There are basically three types of errors: imperfections, non-conformance and omissions. Imperfections are deviations in details that have no affect on the assembly or facility (Davis and Ledbetter, 1987). They require very little correction or can be left as an acceptable condition. There is no cost adjustment or time delay. These errors are generally not recorded, only identified in the As-built drawings for future knowledge. Non-conformance errors are those that do not meet the

specifications and require corrective action (Davis and Ledbetter, 1987). These errors are produced through poor project scope, rework by the contractor or design errors. The final error is an omission of any part of a system that has been left out resulting in a departure from the established requirements. This includes design and construction (Davis and Ledbetter, 1987). In terms of design only, it is necessary to determine if the error(s) were due to negligence by the designer, which will determine if he is responsible financially for any cost impact due to the error.

Definition of Design Error

From the evaluation above a simple definition of design error is "a deviation from the plans and specifications." It is not the intention of this definition to include any cost or schedule growth or insinuate its root causes or legal responsibility. It is the responsibility of the owner, designer and contractor to establish the criteria in order to make a reasonable determination for responsibility. The survey shows a common theme, that of a mistake or error in the design. The survey also indicates several reasons why design errors exist and who cause them. This provides evidence that there is not a concise definition within the construction industry. Table 2-1 lists a sample of the different responses to the definition of design error.

DEFINITION OF DESIGN ERROR

Owner response

1. An error or omission in the plans and specifications which must be corrected in order to provide a facility which is complete and useable, and which achieves the design intent.
2. A reasonable prudent designer neglected his duties, which resulted in an error or omission and caused damage.
3. Errors, omissions and ambiguities in the construction document requiring modifications to correct. Cost for these modifications need not be present for them to be considered design errors.
4. Errors that are reasonably foreseeable during design.
5. Errors caused either by incomplete design data or conflicting design information.
6. Mistakes in drawing details or system design that prevents project from achieving objectives in quality performance.

Designer response

1. Items clearly identified as incorrect or a result of not being coordinated within the documents.
2. Flaws in the project design that can not be constructed or provide the anticipated performance as depicted or specified.
3. Misinterpretations of the owners' desires vs. the program developed by the designer.
4. Plans and/or specifications that are inconsistent or incorrect to an extent over and above the standard expected for the industry.
5. Any item of work in the contract documents which is inconsistent with the design intent, as determined by the architect of record, at the time the documents are issued for construction.
6. Failure by designer to perform duties under the contract which causes a loss by the owner and/or contractor.

Contractor response

1. Mistakes and omissions to the contract documents that affect the facilities intended use.
2. Errors that are directly related to the designer that delay and/or add cost to the project.
3. Mistakes or omissions in the project documentation relating to plans and technical specifications.

Table 2-1. Definition of Design Error.

The responses were primarily reflecting the interpretation of errors as either a non-compliance or an omission. No responses alluded to an error as an imperfection. It can be determined that this was because they do not affect cost and/or schedule growth. The owners' responses stated that errors cause damage and require modifications to cure. Owners also believe that errors keep the facility from becoming complete and useable. Designers' established the definition to include poor coordination or the inability for the facility to perform as depicted. Contractors stated that design errors are directly attributed to the designer and affect the facilities intended use. From this evaluation it is evident that all three agree the design error will effect quality performance.

One response attributed blame for design errors to the owner, designer and contractor through the use of poor quality as-built drawings. At the end of a project the contractor is required to submit an as-built construction set of drawings to the owner to document actual construction created by changes to the original design documents. The as-built drawings are provided for the benefit of the designer and contractor where future efforts may be influenced by this project. Design errors could occur in future projects because:

1. Previous as-builts were not accurate. The fault would lie with the previous project participants.
2. The designer of the new project did not put the "good as-builts" to proper use.
3. Designer did not conduct adequate field investigation to substantiate as-builts.

It is not the intention of this report to determine the industry definition of design errors, but rather to show the diversity of its possible meaning within the industry. It is clear that the principle parties must agree during the design phase as to the understanding of a design error, its severity and how to correct the discrepancy.

III. CONSTRUCTABILITY

The owner, designer and contractor all have different interests in, or uses for the design of a facility. But what they do share is the commitment to complete the project safely and within a given budget and completion time. Tucker and Scarlett (1986) stated that there are many problems that are encountered during the construction phase such as: constructability, maintainability, late or inaccurate drawings and expensive changes during construction. There are research initiatives being conducted to identify the problems with design constructability, looking primarily at the quality and efficiency of the design and how to reduce design errors. The Construction Industry Institute defines constructability as the "optimum use of construction knowledge and experience in planning, design, procurement and field operations to achieve overall project objectives.

Sources of Changes

What actually causes cost and schedule growth in projects? There are many factors that can be attributed to the causes that effect construction costs and schedules. It has been documented that "changes" during the project create the majority of cost and schedule growth. It is the impact of these changes that need to be monitored in order to determine the net effect on cost and schedule overruns. In a report conducted by Hester, Kuprenas and Chang (1991), a consensus showed the numerous types of "sources of changes" on construction projects. A list of those is provided in Table 3-1. They clearly documented that the most common type of change was an alteration to the project scope. This included unexpected developments at the site (unforeseeable conditions) as well as a change in the owner's requirements. Through the survey for

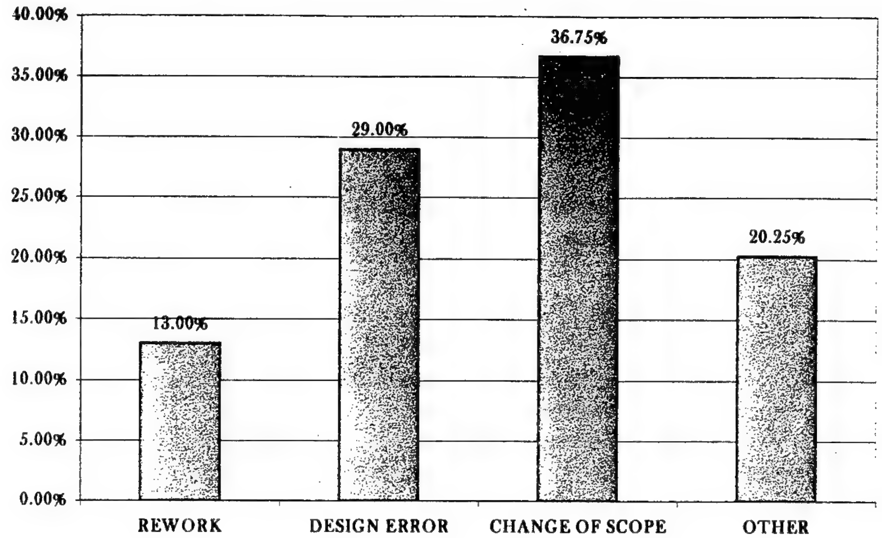
SOURCES OF CHANGES	
❖ Clarification of work	❖ Substandard Work
❖ Additional Work	❖ Change In Scope
❖ Changed Site conditions	❖ Unforeseen Conditions
❖ Substitutions	❖ Owner-caused Delays
❖ Ambiguous Specifications	❖ Lack of Knowledge
❖ Omissions in Specifications	❖ Gaps in Contract Documents
❖ Design Errors	❖ Increased Scope
❖ Differing Site Conditions	❖ Project Rhythm Interrupted
❖ Delays	❖ Discretionary Changes
❖ Improper Actions by Contracting Officer	❖ Value Engineering
❖ Deficient Site Investigation	❖ Mandatory Changes

Table 3-1. Sources of Changes (Adapted from "Construction Changes and Change Orders: Their Magnitude and Impact," 1991)

this report it is documented that change of scope is the largest contributing factor to cost growth and time extension. However, these changes are often difficult to control due to the nature of the owner's vicissitude in requirements. It is a marketing strategy based on the Pareto principle, that in order to reduce costs you do not necessarily attack the condition that contributes the largest percentage of the problem; rather you attack the problem that will have the greatest overall effect on reduction. Figure 3-1 shows the average percentage assigned to the three main categories of project changes. The three main categories being rework, design errors and change of scope. The "other" category refers to changes due to codes, value engineering, weather and unforeseen conditions.

Of 100% of project change orders, 36.75% is attributed to change of scope. These are changes due to the owner altering his requirements or unforeseen conditions at the

Figure 3-1. Average Percentage of Errors per 100% of Project Changes



job site. There is little control over these situations. Design errors made up 29% of the contribution to project changes. Designers and contractors have the managerial tools to reduce this percentage significantly thus, having a major impact on reducing project changes. The same condition holds for the contractor's control over rework on the job site.

The percentage for other dealt with project changes associated with code requirements, unforeseen conditions, weather and value engineering. Code requirements are the responsibility of the designer and are part of the design review. Codes are subject to interpretation. That interpretation is not set in stone and can be overturned even during the construction phase. As stated earlier no one can control unforeseen conditions assuming there was proper field investigation and all the information concerning the project was disseminated. No one can control the weather, only working conditions in the weather.

Figures 3-2 and 3-3 show the percentages of project changes with respect to the values assigned by those surveyed. In Figure 3-2 the correlation of responses among the principle parties shows that change of scope is the major percentage of project changes. A major factor for this is the overwhelming response by designers. In the category of design errors, owners and contractors regarded design errors as the major reason for project changes while designers suggested that these were the minimum cause of project changes.

Figure 3-2 provides the individual relationship of the principle parties and their responses to the project change percentages. As indicated from the figures the two major project changes are scope of work and design errors. The following sections of this chapter will discuss these topics and evaluate responses from the survey.

Figure 3-2. Project Change Percentage Ratio per Control Factors

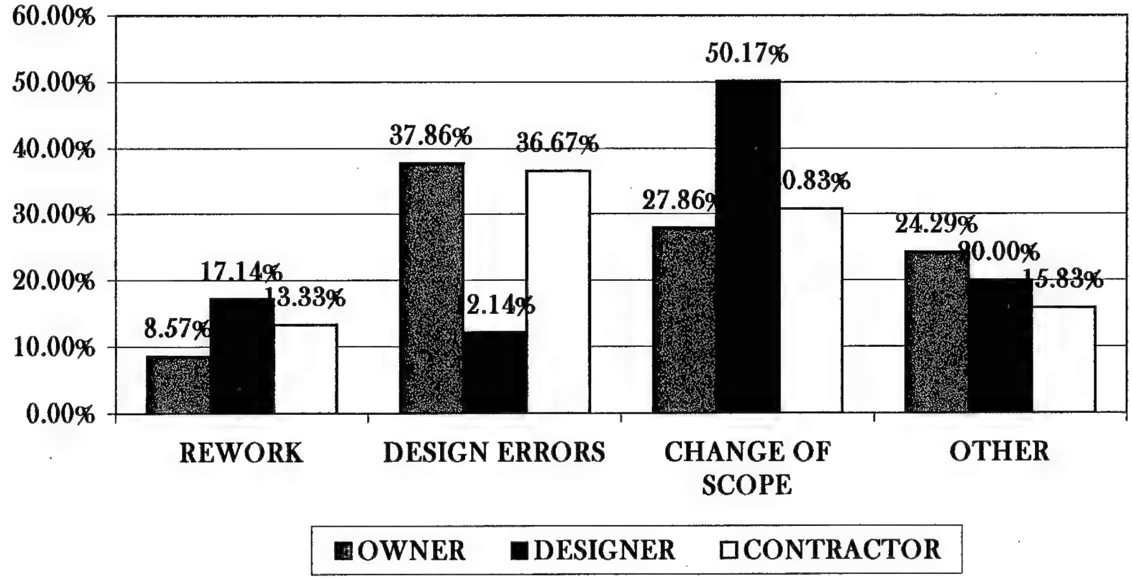
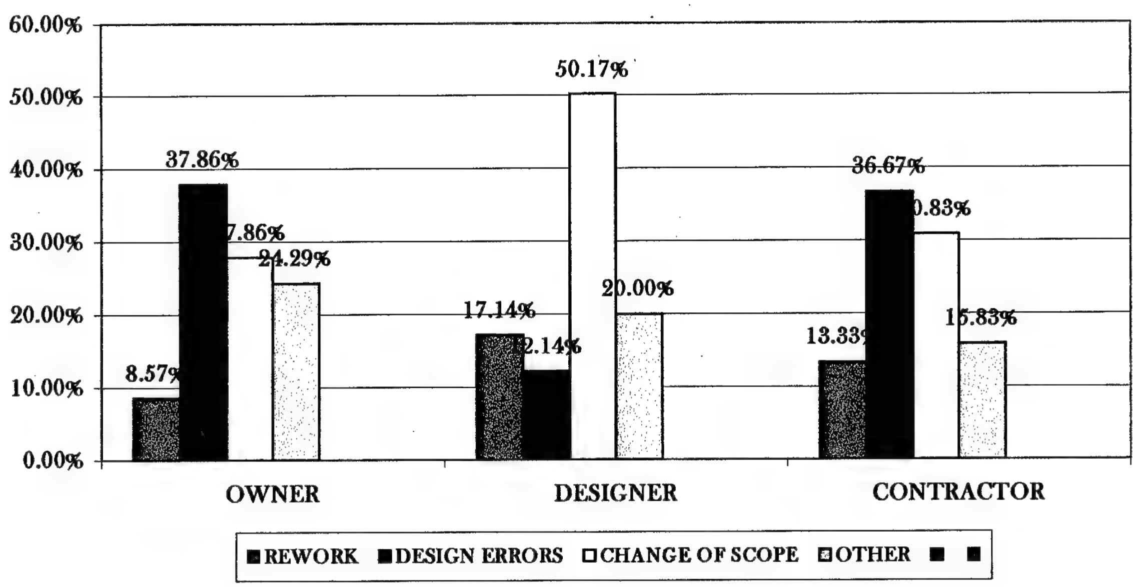


Figure 3-3. Project Change Percentage per Principle Parties



Scope of Work

It is the goal of the owner to select a designer who will develop a project to meet his objectives and priorities or scope of work. A poorly defined scope of work will create undesirable results, increase the cost and time of the project and cause dissention between the owner, designer and contractor (Chalabi, Beaudin and Salazar, 1987). Serious problems occur when the owner, designer and contractor do not have an identical understanding of the scope definition. This requires greater communication between the project participants. Poor scope definition is likely to result because, "the emphasis in today's economy is to spend as little money as possible to get as much as possible in the shortest period of time possible" (Chalabi, Beaudin and Salazar, 1987). Without a good idea or what is to be done:

- Proper planning cannot be accomplished
- Realistic schedules and budgets cannot be produced
- Many changes will be made as the project progresses

(Diekmann and Thrush, 1986)

Scope definition is also dependent on the owner's knowledge. An unknowledgeable owner depends on other members of his management team to ensure a quality product. These owners have no interest in the design phase and are not concerned with any differences that may occur during the construction. There are some owners who do not know how to read a set of drawings, making it more difficult to explain the concept as perceived by the designer. A knowledgeable owner is sometimes considered a designer's and contractors best client. He knows what he wants and continues to monitor the program. Sometimes owners perceive their role in project control as giving direction to the project team and monitoring the progress by being on

site (Diekmann and Thrush, 1986). The degree of participation on behalf of the owner is another item that should be discussed up front.

It is argued that the selection of the designer is the most important variable that influences the design outcome. Therefore, it is a very important responsibility of the designer to determine the owner's objectives and, through the design phase accurately reflect the owner's project requirements through development of plans and specifications. It is essential that the designer and the owner then fully review the preliminary package in order to ensure that the designer has understood the owner's objectives. It is now the responsibility for the plans and specifications to relay the intentions of the defined project scope to the contractor. Now, an undesirable situation occurs: the contractor has not shared in the planning and concept of design, traditionally discussed only between owner and designer. He can only rely on his past construction experience to try to interpret and understand the reasoning of the owner and designer when confronted with a problem. From the research by Chalabi, Beaudin and Salazar (1987) the contractors responding to the survey stated, "We can build whatever the designer gives us, in spite of the contract. It will just cost more." The contractor is able, during the bidding process, to inquire about problems that are very obvious. But during those few weeks he is concentrating on developing a bid and not reviewing details for errors. It is not to insinuate that the contractor cannot think for himself but rather that communication is a key ingredient. Contractors are willing to bid on jobs with poor scope definition so they can get the job. Because of the uncertainty surrounding the work that is produced by an ill-defined scope, a greater amount of communication is needed between owner, designer and contractor and their management personnel (Diekman and Thrush, 1986).

Scope Changes

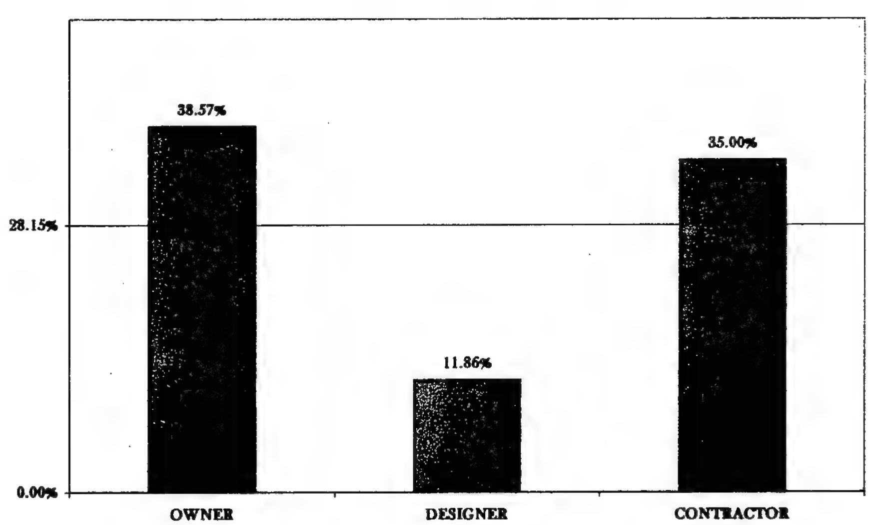
Changes to the scope during construction are another growth producer and can lead to design errors. As defined by the Construction Industry Institute, a change is any event that results in a modification of the project work, schedule or cost. Owners and designers initiate changes to reflect changes in project scope or preferences for equipment and materials originally specified (Hester, Kuprenas and Chang, 1991). The project may be modified to accommodate unexpected developments at the site or in the owner's requirements. In the government, many projects are designed and then funded years later. In that time frame the customer for the facility has changed and along with it his requirements. The new owner will try to have changes made to the design package. If approved, this requires the designer to make major modifications in a short period of time thus providing avenues for errors. The survey confers that a majority of the changes to a project, 36.75%, come from change of scope. If the owner is willing to pay for the changes he requires then there is no problem. He must be able to accept an increase in the construction schedule as well.

The contractor considers unavoidable changes as scope changes due to the unforeseeable condition that exists at time of construction. Included are the changes that are thought to be design errors but are created due to lack of scope definition not provided to the designer by the owner.

Design Errors

It used to be that designers were handled with kid gloves and not held financially responsible for any errors or omissions in the construction documents. Rarely did the owner look to the designer, but would simply pay for the change and tell the contractor to make it happen. Today owners and even some contractors are going after the designer for errors, omissions and ambiguities to the drawings. From the earlier discussion concerning the Pareto principle, it is clear through the figures in Figure 3-4 why it would be beneficial to reduce design errors. On the average those surveyed indicated that design errors make up 28% of the contract changes. Considering all the administrative and legal costs associated with correcting design errors they make an attractive target. From the owners' response that 39% of project changes are caused by design errors, there would be substantial savings for them in reducing design errors. The same is true for the contractors who consider 35% of contract changes are caused by design errors. In today's market it is not economically feasible for the owner or

Figure 3-4. Percentage of Change Orders caused by Design Errors



contractor to accept the overhead costs that an error associates with a project.

It is increasingly difficult to prove that the designer is responsible and should cover the costs. But it is easy to remember errors from past projects and use this as an historical precedence to determine an expectable level of requirements for the next project. When a contractor is accused of deficient work, there is no proof required for the immediate correction to the work. He is required to fix the problem on his own time and with no compensation.

There are several contributing factors that create a catalyst for the making of design errors.

- Designers lack of construction knowledge and experience
- Insufficient funds to create quality documents
- Insufficient time to create and review quality documents
- Lack of coordination between principle players and other disciplines
- Ill-defined or unclear scope of work
- Human error

These factors will be discussed in Chapter Six.

Davis and Ledbetter (1987) consign to the required establishment of design quality control and/or assurance to become an integral part of design. As stated earlier, the designer does not warrant that it's design, drawings, specifications and other services will be free from error. Therefore, the principles to a construction contract need to establish up front through a comprehensive quality control program what is an acceptable amount of design errors and what they constitute. Burgess (1984), in defining quality assurance, gives some basis from which to understand quality design: as "those planned and systematic actions taken to provide confidence that the product design will satisfy the requirements of its intended use." Davis and Ledbetter (1987) provide insight as to whether a reduction in errors is a correlation with improved design

quality management or just taking time to do it right. It seems that today we need to rely on improved design quality management, due to the factors of cost and time, hoping that the services were produced right the first time.

IV. RESPONSIBILITY FOR ERRORS

The survey used in this research indicates overwhelmingly that the designer should be held responsible for the design errors and pay for the correction. If the designer created the errors through the production of the drawings and specifications then he is responsible. Before it is determined who is responsible for an error it should be clearly documented what type of error it is and what caused it. The contractor can not be held responsible for design errors unless he was involved in the design review and provided direction of means and methods for construction to design by. Errors that stem from incomplete data or conflicting design information can be shown the responsibility of the owner. With an ill-defined scope the designer will attempt to produce a design that meets the owners objectives and requirements. A design package will be presented for approval and if the owner does not give the designer a clear scope of work, even after an "approved for design package" is released, it then becomes the responsibility of the owner.

Proving Negligence

Negligence by the designer is defined as failure of a professional to exercise the reasonable care and skill observed by members of their profession in the same or similar circumstances. The Government requires that the costs of design deficiencies be documented for recovery.

The Armed Service Procurement Regulation requires that whenever a construction modification results from an error or an omission in plans and specifications, the construction engineer shall consider and document in the contract file the extent to which the A/E is responsible.

Government Burden of Proof

In order for the Government to hold a designer financially liable for an error, it must show that under similar circumstances, a reasonable prudent designer would not have neglected his duty of due care which results in error or omission and causes damage to the Government. The Government bears the burden of proving each of the following:

1. There was a deficiency in the designer's work
2. The deficiency was a result of an error or omission by the designer including a breach of it's contractual duty of skill and care
3. The error or omission resulted from negligence of the designer
4. The error or omission resulted in damages to the Government (additional costs) above that which would have been incurred if the original drawings or specifications had been correct

This process is both time consuming and expensive. It was for these two reasons the government reduced its direction to pursue A&E liability. Today the government is revitalizing its liability program due in large part to shrinking construction budgets and the quality process of choosing firms to produce construction documents.

V. FACTORS THAT CONTROL DESIGNS AND CONSTRUCTION

Constructability Pyramid

There has been a huge swing in the factors that dictate the control of design and construction. In the early 1900's owners demanded high quality facilities to show their wealth or prestige to the rest of the world. The structure was to make a strong statement of longevity and style. They understood that this quality took time and would cost considerable money. The constructability pyramid took the form found in Figure 5-1. Cost was a major consideration but it did not control the project as much as the other factors.

Figure 5-1. Constructability Pyramid of the Past.

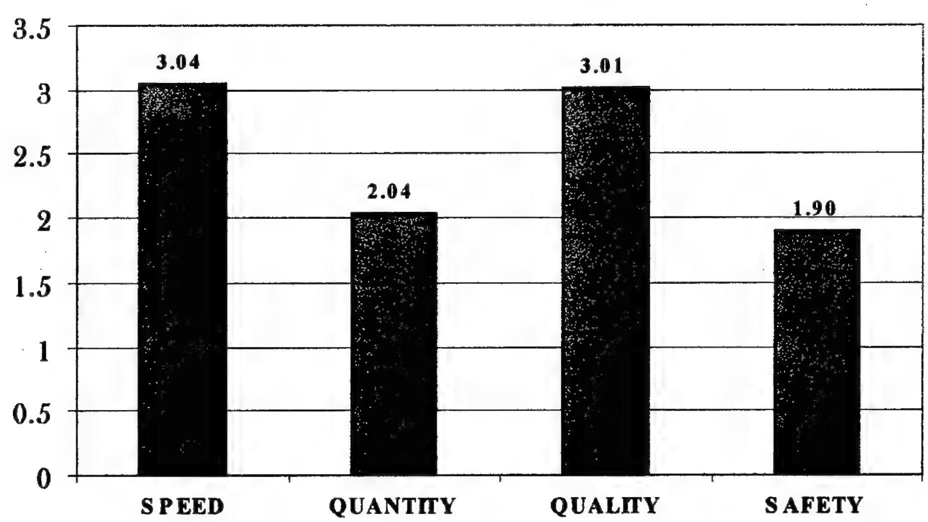
Today, we want it "now", we want it "cheap" and we want "a lot" of it, and somehow during the process, "do not get hurt accomplishing it." Unquestionably the number one factor that controls design and construction today is cost. Cost is an important

consideration in any design evaluation, but looking at cost alone does not consider the effects of design upon construction of operations (Tucker and Scarlett, 1986). Therefore, it was the intention of the survey to have the principle parties prioritize the other major controlling factors of Speed, Quality, Quantity and Safety. Respondents were asked to prioritize the list of control factors in order of importance on a scale of 1 - 4, with 1 being the most important. A scoring value was then assigned to the responses as follows:

Prioritization order:	1	2	3	4
Scoring value:	4	3	2	1

The total scoring value was determined and divided by the number of responses for each category. The overall results are provided in Table 5-1.

Table 5-1. Average Relationship of Control Factors



From the data gathered, the factors of the construction pyramid are reorganized and are prioritized as shown in Figure 5-2. The intention of this section is to discuss the criteria for the prioritization.

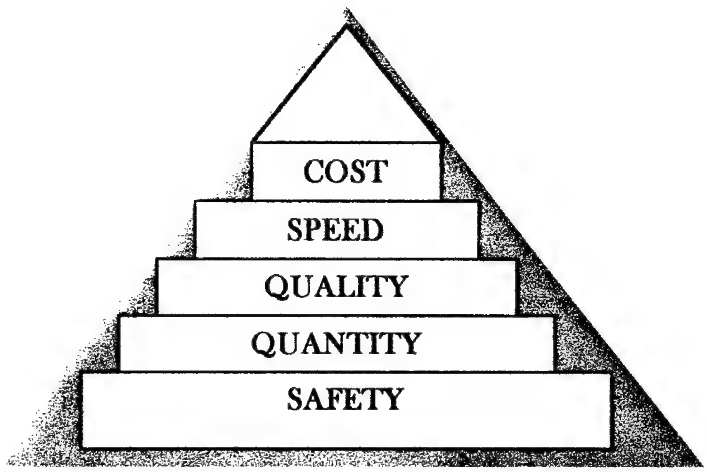
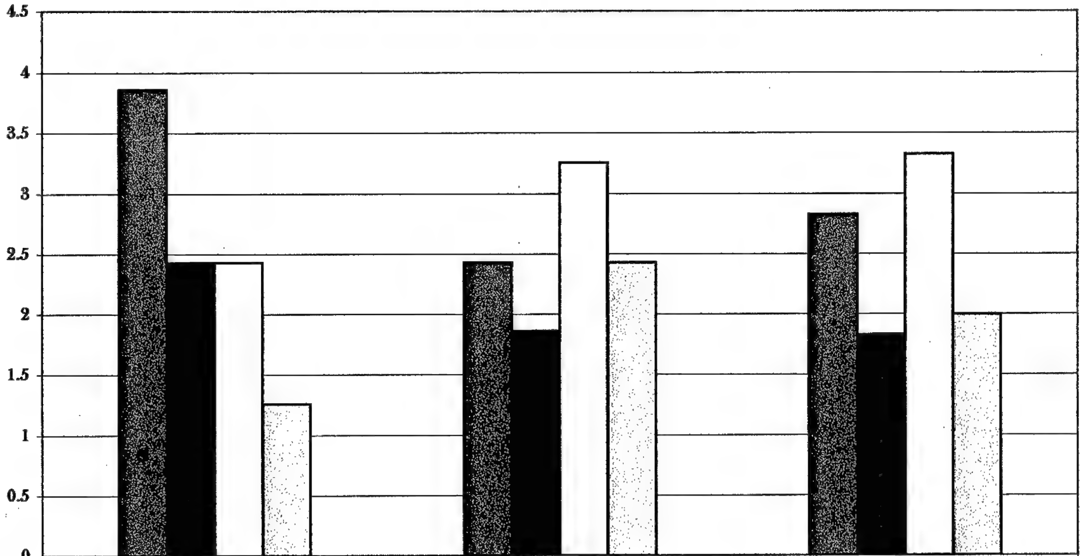


Figure 5-2. Constructability Pyramid as Determined by the Principal Players.

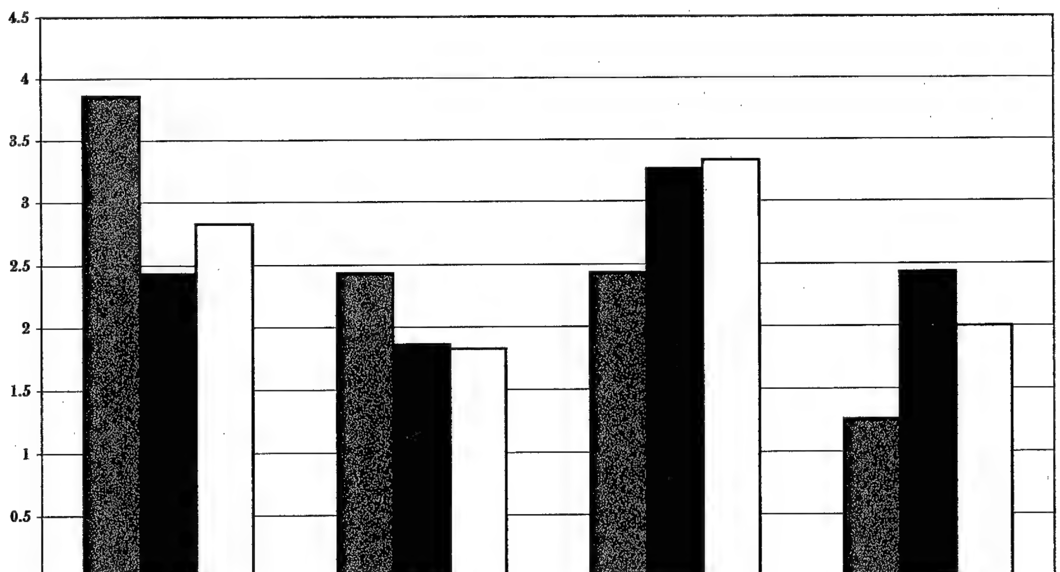
Table 5-2 provides a breakdown of the responses for the owners, designers and contractors showing their collective importance towards each of the controlling factor. Table 5-3 graphically shows each of the controlling factors and the value assigned by the owners, designers and contractors. The succeeding sections provide an assessment of each of these controlling factors based on interviews with some of the respondents.

Table 5-2. Relationship of Importance of Control Factors to Principle Parties



	Owner	Designer	Contractor
Speed	3.86	2.43	2.83
Quantity	2.43	1.86	1.83
Quality	2.43	3.26	3.33
Safety	1.26	2.43	2.00

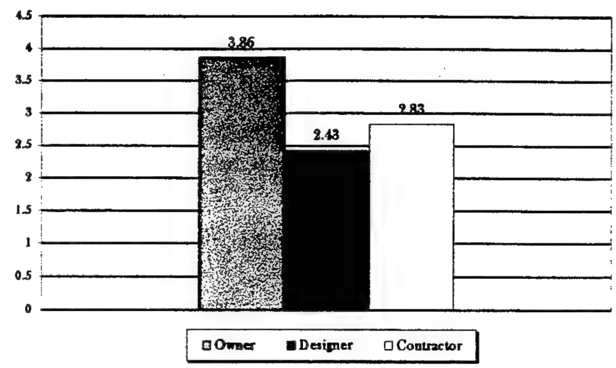
Table 5-3. Relationship of Principle Parties to Control Factors



	Speed	Quantity	Quality	Safety
Owner	3.86	2.43	2.43	1.26
Designer	2.43	1.86	3.26	2.43
Contractor	2.83	1.83	3.33	2.00

Speed

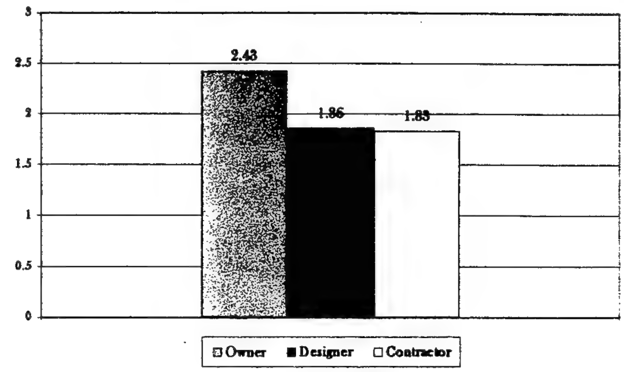
Table 5-4. Speed Control Factor



The data indicated that the major concern for project accomplishment was speed. This is particularly true for the owners. For example, in the hotel industry, for every day lost not operating there is a major loss in convention and lodging revenue. For commercial owners the faster the finished facility can generate funds the quicker the pay off, profits are achieved and other investments can be initiated. Speed was not as critical to the designer or contractor. The designer prefers more time in order to finish drawings and to coordinate with other disciplines. This can assure that the design development will be driven by quality and not time. The time frames require too much too fast thus producing the fuel for errors. The designer has to decide which drawings will provide a product to satisfy the requirements. The analysis of time and its relation to Computer Aided Drafting (CAD) will be discussed later. It will be noted here that the development of FAX machines and computer drafting became enemies to the designer because now the owner expects results overnight. The design professional must then make decisions that may be less than desirable. The issue of time for the contractor was primarily the brevity of preparing bid documents. Whereas, the designer is given several months to prepare the documents, the contractor is only given several weeks to review and cost out the project.

Quality

Table 5-5. Quality Control Factor



The next level down on the pyramid is quality. From the interviews conducted this is the major issue involving the reduction of design errors. From the Construction Industry Cost Effectiveness Report (1983), "by common consensus and every available measure, the United States no longer gets its money's worth in construction, the nation's largest industry." They continued that this condition is caused by the "inadequate and outmoded management practices." There have been great strides in getting better value with the use of Quality Control and Quality Assurance packages. It is evident through this survey that there is still room for improvement.

The data from the survey shows that designers considered quality to be the major factor in the relationship of the other variables and of higher concern than the other parties. There would be reason for concern if the data did not support this evaluation. The quality of the documents created by the designers establishes the quality the contractor will demonstrate on the job site. This substantiates the design documents as the catalyst for the entire project. It is obvious, the greater the quality of drawings the easier it is for the contractor to conform to the owners objectives and requirements. Quality criteria affect all phases of the design process producing a quality constructed facility. This process is shown in Figure 5-3.

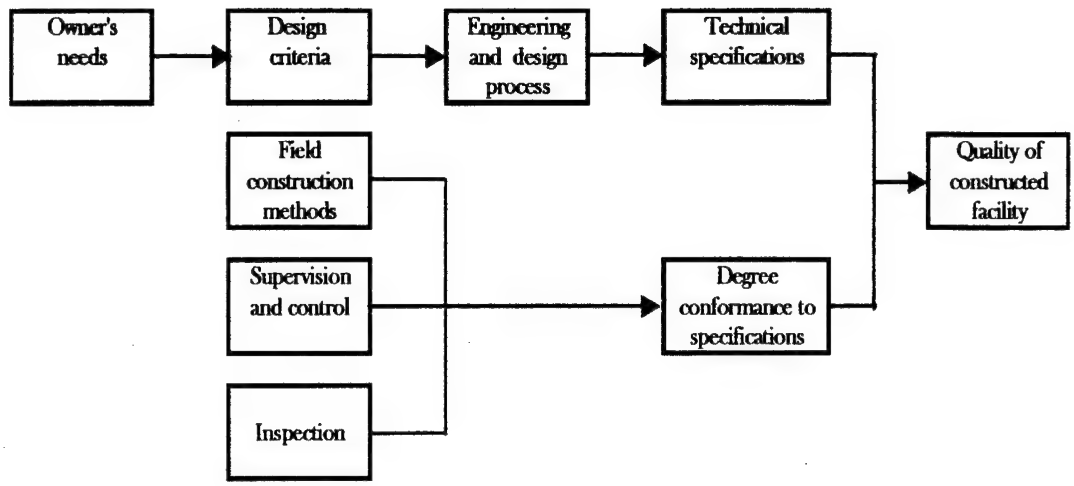


Figure 5-3. Elements of Quality Design Process. (Adapted from Elwood G. Kirkpatric, Quality Control for Managers and Engineers, John Wiley & Sons, Inc., New York, 1970, p.5)

There are several reasons why quality is not easily or automatically achieved during the construction process:

- ❖ The requirements themselves are not always adequately described
- ❖ The environment for construction is unstable
- ❖ A construction project may be driven by cost or time and considerations of quality may be subservient to considerations of cost and time.

(Davis and Ledbetter, 1987)

The Construction Industry Institute states that quality is a "conformance to established requirements." It is not a measure of goodness. In the report by Davis and Ledbetter (1987), one of their conclusions consisted of the development of a simple formula to determine the cost of quality (T) in the design, construction and start-up phase of a project. It consisted of two parts: the cost of quality management efforts (M) and the cost of correcting deviations (D).

$$T = M + D$$

The cost of the deviation focuses on not only direct and indirect costs but also the impact deviations may cause. These impacts would include the delay or disruption to one activity that may or may not have an effect on another and any litigation it would endure.

Figure 5-4 commonly shows the relationship between quality costs and percentage of deficiencies. It shows the conventional wisdom that an increase in expenditures on prevention and appraisal is accompanied by a decrease in the percentage of defects, or a higher quality level (Davis and Ledbetter, 1987).

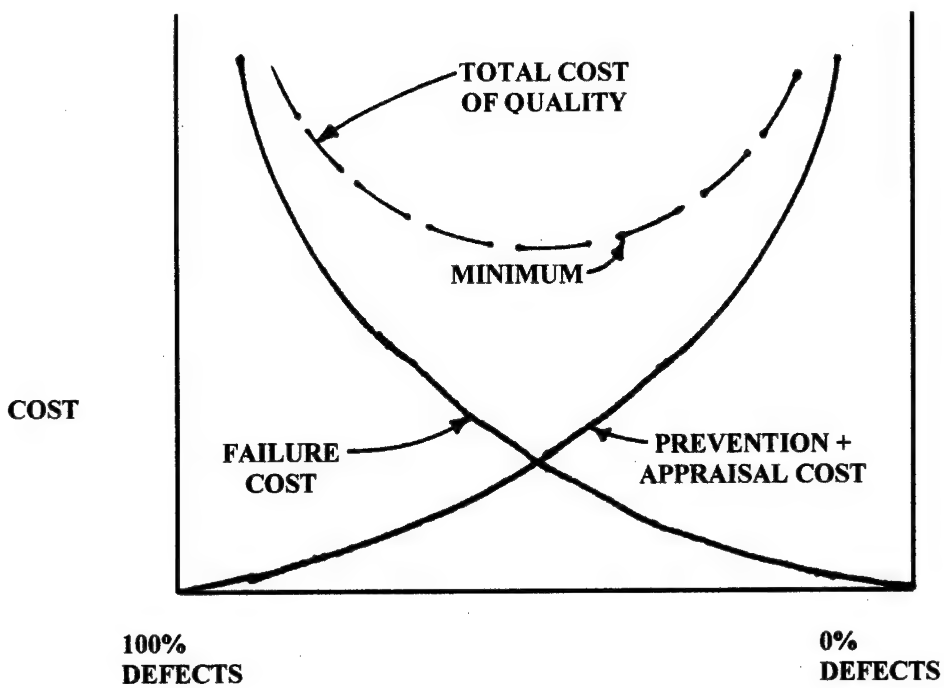
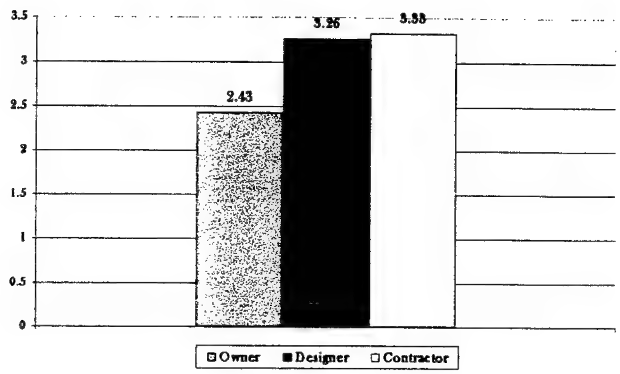


Figure 5-4. Cost Versus Quality Level - Classic View (Adapted from "Quality Cost and Profit Performance" 1984)

Quantity

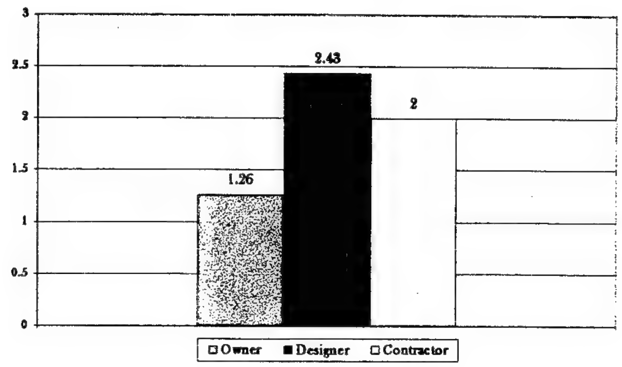
Table 5-6. Quantity Control Factor



Quantity is defined as a property by which something is measured. The owner responds to the idiom of wanting more for less. Davis and Ledbetter (1987) determined that today the construction industry is looking for quantity in design with less emphasis on quality. It is assumed that the more drawings for a project the less likely there will be ambiguities and changes. According to designers having more drawings is a two way street. Whenever a lot of information is provided it lends itself to more errors. On the other hand more details are covered and the contractor, who appreciates lots of details, can put together a clearer picture of the project. In dealing with the means and methods of construction the contractor is capable of deciphering some details with small errors. When the error repeats itself throughout the document the contractor requires a Request for Information (RFI) to clarify the problem.

Safety

Table 5-7. Safety Control Factor



When confronted with the term safety the general response from designers and contractors in the construction field is, "Safety First." From the data collected it seems safety is not first but last. From the interviews conducted it is by no means indicated that safety is not important on the job site rather it is not as high a priority in the design phase. Designers are required to design according to building codes, life safety codes and zoning regulations. What is not considered is the design of safety with regards to actual construction techniques. It has been the responsibility of the contractor to establish all safety criteria in accordance with the construction project.

Various factors such as: the constantly changing site conditions and personnel, the temporary nature of the workplace facilities, the existence of attitudes and practices that are counterproductive and or unsafe and a variety of other lesser factors combine to make the construction site a very hazardous place to work. The problem in construction is compounded by the intensely competitive nature of the industry, where short-run expediency in cost-cutting areas such as safety and health often seems attractive and even necessary for business survival (Barrie and Paulson, 1992). Last year alone there were 2100 deaths and 205,000 disabling injuries in the construction industry. There have been great strides to eliminate deaths and accidents but there are

many factors that are out of the contractors' control. Prior to the contractor starting construction on government jobs, he is required to provide a comprehensive safety plan. Work can not proceed until the safety plan is approved approved. During construction the contractor is governed by OSHA regulations and is heavily fined for producing an unsafe action.

The contractor is solely responsible for the means and methods for construction. The plans and specifications for the project govern his safety plan. The designer only crosses the responsibility line when he tells the contractor how to do it instead of what to do. There have been attempts by OSHA to increase the design professional's role and exposure to prosecution and liability for construction safety (Hinze, 1997). This is perhaps why designers are reconsidering that safety will be an extremely important factor in the control of design.

Partnering

How does Partnering relate to design errors? The purpose of Partnering is to open a line of communication between all parties involved prior to commencement of construction. The Construction Industry Institute (CII) defined partnering as:

> A commitment between two or more organizations for the purpose of achieving specific business objectives by maximizing the effectiveness of each participant's resources. This requires changing traditional relationships to a shared culture without regard to organizational boundaries. This relationship is based on trust, dedication to common goals, and an understanding of each other's individual expectations and values. (Construction Industry Institute, 1995)

Prior to partnering, the design input was between the owner and designer and any resolution from contract issues would be between owner and contractor. The goal is to prevent disputes and reduce litigation. To create a cooperative attitude, each party must seek to understand the goals, objectives and needs of the other - their "win" situation - and seek ways that these objectives overlap (Edelman, 1991).

The following are benefits that, according to the Associated General Contractors of America (1991), stake-holders achieve from partnering:

Owners:

- A better quality product as a result of focused energy on the e construction project rather than misdirected towards adversarial issues.
- A lower construction cost by reducing delays, cost overruns and administrative costs in tracking controversial and adversarial issues.
- Reduced exposure to litigation by maintaining open communication and resolving disputes quickly.

Designers:

- Increased role in the prosecution of the work. Produces an increased opportunity for value engineering suggestions and/or constructability changes.
- Opportunity for a financially successful project is increased when designers have a voice in the design process for the project.
- Controlled involvement in the project reduces their exposure to litigation through dispute resolution strategies.

Contractors:

- Increased productivity for the project crews. Expedited decision making process allows reduction/elimination of delays and realigning of work. The crew can maximize their work effort.
- Realize better schedule and cost control for the project through the reduction/elimination of delay costs and cost overruns.
- Realize lower administrative costs through the reduced exposure to litigation by maintaining open communication with the owner.

All parties involved in partnering must first understand the other member's interests in the design of a facility. Once achieved the design team can focus on the objectives and requirements of the project in order to produce a quality facility. A cooperative management style allows all the parties to agree to specific management procedures and definitions for the project. Further, they can discuss the quality of the design and address any discrepancies that need further investigation. This will reduce confrontation in the field and not hinder the contract schedule. Daniel Burns, Chief of Construction Operations, COE North Pacific Division stated:

"The end result of [of current 'adversary management'] is a continuing upward spiral of risk and cost: risk of the contractor going broke, risk of projects taking longer than necessary for completion, and risk of significant cost overruns. These costs do not go to productive facilities, but instead to overhead, litigation, and contesting experts. Partnering seemed to offer the opportunity of harnessing capabilities, talents, and positive energies of both owner and contractor groups and focusing them on mutually agreed-upon goals. It offered the opportunity for all parties to change preconceived attitudes in order for both to win in the long run." (Edelman, 1991)

This relationship also lends itself for discussing the quantity of drawings required and if any design details lead toward unsafe practices. The contractor can feel that he has some contribution to the design input and have an influence on the design documents related to the means and methods of construction. This has been proven to reduce the number of changes due to errors, omissions or ambiguities in the design (Construction Industry Institute 1996). The contractor will be able to reduce delays and rescheduling and can independently make intuitive decisions in the field. The

owner can once again hear the stated objectives and priorities and ensure everyone is on track.

Implementation of Computer Aided Drafting

Through the growing evolution of the microchip, the computer has become an essential part of everyday life. This includes the integral applications of project planning and construction. With its advanced technology, universities have made computer drafting a required course. The registration exam for architects has become computerized and requires the individual to test his efficiency to design with a computer. Are they being tested on computer skills or design? The answer is both. "There is the need for such people to become more knowledgeable about the capabilities and limitations of computers and their related software for construction planning and control," (Barrie and Paulson, 1992). As of this report the professional exam for engineers has not included any related design efforts.

With the implementation of CAD, it is important at this point to see if it has aided in reducing the number of design errors and improving the production of design documents. A reoccurring comment from those interviewed in this research stated that if a design error is not corrected and the detail is stored in the database then the error is destined to repeat itself. In a report by Choi and Ibbs (1989), CAD offered eight "downstream" benefits that associated major savings with computerization. "All these items translate into improved cost effectiveness in final products of engineering and construction." These are listed in Table 5-7.

DOWNSTREAM BENEFITS TO COMPUTERIZATION
❖ Development of an electronic database valuable for continuous facility management. ❖ Better materials management and control. Avoidance of shortages and surpluses. ❖ Improved constructability through easier incorporation of construction knowledge into design. ❖ Improved construction schedules and overall projects schedules. ❖ Less field rework and fewer changes. ❖ Improved plant operability and flexibility for owner needs. ❖ Better construction and plant safety. ❖ Lower "life cycle" plant costs by reducing operating and maintenance costs, including energy costs, through additional engineering capabilities. ❖ Improved proposal and bidding process. ❖ Better communication capability between and within engineering and construction departments.

Table 5-7. Downstream Benefits to Computer Aided Drafting (From "Cost Effectiveness of Computerization in Design and Construction, 1989)

Two of the benefits that are associated with design errors provide a different outcome from the responses to the survey and interviews. They are discussed below.

"Less field work and fewer change orders." This statement reflects concerns for the area of design errors. According to the questionnaires 100% of the responses declared that that CAD had not reduced the number of design errors. The computer can not indicate that an error has been made in a detail drawing. That can only be determined through eyes on review. It is human involvement that created design errors whether by hand drawing or computer. Someone has to provide the input to the computer. Now

that CAD has developed an increase in drawings so too has it increased the number of details and possibility of errors.

The perception among owners and contractors is that CAD will reduce design time and increase production, whereas the opposite is true. Designers are given the same or even less time to design and put the documents out on the street. Owners assume that with CAD the time required to create design documents should be less. CAD will require less time if the facility is a prototype of another project.

From the interviews conducted, owners commented that production in design has been improved only somewhat with regards to making a lot of corrections to the documents. Designers have argued that the initial design of the project takes just as much time on the computer as it would to draw by hand. Production time is only improved when, for example, floor plans are copied to develop reflected ceiling plans or to make changes to an item that is affected on several floors of a multi story project. From this point of view CAD has greatly improved the production capabilities. Contractors commented that computers have greatly improved production in terms of scheduling work, estimating, and procurement and in some respects quality control.

Designers have stated that the primary reason CAD is adopted and used is because the owner expects it. The initial cost for a firm to computerize its operations is tremendous with the hardware, software and training. The software is constantly being updated, which requires purchasing and retraining. This is an issue that must be accepted and continually optimized.

With hand drafting there was a conscious effort to take drawings to another location and wait for drawings to be reproduced for review. The computer allows the simple push of a button on the keyboard to create a plot of many drawings without waiting.

Perhaps this improves production but it also creates an increase in the reproductions created for the project. The cost of reproductions is passed on to the owner.

"Better communication capability between and within engineering and construction departments." The coordination of documents between disciplines has improved, although the improvement has not been as great as expected. When the engineer E-mails or gives a disk of design data to the architect, the architect then prints out the information in order to visually coordinate the drawings. It still takes an eye on review to coordinate all the other disciplines drawings. Presently the computer software does not have the capacity to recognize discrepancies between the different drawings. It is not possible to view the drawings on the computer screen because not all of the drawings will fit onto the screen. What the screen does show is a multitude of layers of drawings creating confusion. It is very difficult to pick out errors in details on the viewing screen. The drawings must be printed out so coordination can be conducted. When a deviation is located a comment is made and the disk is sent back to the engineer for revision.

VI. MAJOR CONTRIBUTING FACTORS TO DESIGN ERRORS

When asked on the survey what are the major contributing factors to design errors the overwhelming theme was lack of coordination. Responses to this question are provided in Table 6-1. The primary focus was on the lack of coordination between the different disciplines and consultants within the designers' team. It is well known that the coordination of the other disciplines is the hardest thing to do and often is ignored due to the speed which the contract documents are required to hit the street. The lack of coordination due to speed exists in both the public and private sector. Of particular interest was a response by a contractor that the owner had not coordinated with the designer. Coordination between the owner and designer is the critical factor in establishing a quality product. Lack of coordination stems from either an unclear or ill-defined scope of work. An unclear scope is information that is indistinct or much is left to the designers' imagination. An ill-defined scope is information that is not properly conveyed or that the objectives and/or requirements are not specified precisely.

The Government responded on several occasions that the designer relies too much on the government to review the drawings. On the one hand, as the owner's representative, it is the government's duty to review and determine that the designer is within the scope of the project. This is usually done at 30% completion of the drawings. It should not be the government's role to decipher if the documents are free of error. That is the duty of the design professional. On private projects the A&E requires the owner to sign off on the design package, out of courtesy a set is sent to the owner at completion so he can follow the progress. The unknowledgeable owner waits

for the construction to get well under way before determining if the project is meeting his objectives and requirements. The knowledgeable owner studies the documents and tries to stay ahead of the construction sequences.

In response to the survey concerning what major factors contribute to design errors, 62% stated that there was insufficient time to create and review quality documents. It is perceived that if the designer is given appropriate time to produce accurate and usable documents then there will be adequate coordination. If the objectives and requirements of the owner are achieved then a quality product will prevail.

Compensation for the designers' services has always been a topic of debate. Designers have traditionally received a 6% fee of the estimated government cost of the project. Owing that the designer will ensure a profit, the amount of drawings produced will reflect the budget and perhaps the quality of drawings.

Of particular concern are the responses indicating the designer's lack of construction knowledge and experience. Young design professionals are engaged in an internship program where seasoned professionals instruct them on the relationship between details and construction methods. Sitting in a drafting room lends little chance to learn construction techniques. From discussions with those surveyed there seems to be no correlation between the drawings and actual construction techniques. "That is the danger in just copying details from a database." To compensate designers try to draw generic details requiring the contractor to fill in the blanks. Professionals must get out into the field and form first hand knowledge of construction techniques. Only then can the designer properly detail the drawing for the particular site and project.

The final reference that was not mentioned but is a consideration is human error. Everyone makes mistakes. Mistakes are made from improper mathematics, speed,

lack of construction knowledge and miscommunication. Firms must take the time to review their work and discuss the project with its documents amongst the team. In the 1800's when accounting firms had the checkers to check the checkers of the ledger books it was to eliminate human error. With computers a common phrase is "garbage in - garbage out." Human error can never be eliminated but it can be reduced with more time allotted to reviews and checking systems.

MAJOR CONTRIBUTING FACTORS TO DESIGN ERRORS

Owner response

- Poor qualification of the A&E. Lack of timely initiative by General Contractor/Contract Manager and trade contractors to control design errors.
- Lack of proper field investigation and document quality control.
- Lack of coordination between disciplines. Owner changing design criteria late in the design process.
- Government spends too much time reviewing the A&E's work. The A&E relies on this review rather than conducting their own.
- Because of funding controls, there lacks a means to implement long range acquisition planning. This results in a more frenzied design to more quickly provide a finished design. Haste makes waste. Plus, spending restrictions for design costs sometimes do not allow sufficient funding to do a quality design.
- Poor coordination and communication within the A&E's design team. Another contributing factor is that the A&E relies on the owner for review of the design package.
- Inexperience of design professionals. Attempt to produce maximum profit by minimizing staff.

Designer response

- Coordination with consultants and Architect.
- Misunderstanding the scope. Time. Lack of communication and coordination.
- Low budgets for design.
- Inexperience of drafting staff. Project Managers not understanding the scope of the project. Owner creating a change of scope late in the design.
- Miss-coordination between lead designer and consultants; and confusion created by owner decisions or indecision's, and in turn lack of time to properly address items in the drawings and specifications.
- Insufficient oversight and design changes late in the process.

Contractor response

- Client not coordinating as to what is required. Designer rushes out drawings before proper review.
- Lack of construction experience by the designer.
- Budget and time pressure on the designer.

Table 6-1. Major Contributing Factors to Design Errors

VII. BARRIERS TO REDUCING DESIGN ERRORS

When it comes time to determine what prevents parties from taking greater steps to reduce design errors, the finger pointing stops and realization steps in. First, all the major disciplines concur, according to the responses in Table 7-1, that the time it takes to produce a quality set of design documents is clearly not enough. At one time in the past someone decided how long a designer should be given to complete a design. What was that based on? Possibly because some designers indicated that they could get the job done faster than their competition so they would get the job. The concern should not be time but rather the quality of the design, and if it takes a little longer to produce then it takes a little longer. The end result will be a complete and useable design that the contractor can understand and use to meet the requirements of the owner. The owner gets a quality product and reduced costs due to limited changes (except owner scope changes) and virtually no litigation.

The difficult thing to understand is that if everyone knows that time is a major deterrent then why isn't something done about it. One Government owner indicated that the excuse of time as a factor is simply a crutch, while 74% of those responding to the survey indicated that time was a major consideration in preventing firms from taking greater steps to reduce design errors. The government constantly deals with end of the fiscal year design packages that must be released or lose the funding. They are at times forced to accept less than coordinated designs. The attitude then is take care of any problems in the field with modifications. As one respondent stated "Done is better than Good."

If designers require and are not given, more time to complete and coordinate the final product and everyone knows that, then why do contractors and owners point fingers at the designer for something he can not control. If the designer does not follow his quality control plan then he most assuredly should accept the consequences of a poor design.

Several of the responses stated that profit motive was a factor. Everyone wants to make a profit. And how is this quest satisfied? Finish ahead of time or just get done the necessary items in order to put the project on the street and get it built. If it meets the owner's requirements then obviously they have a quality product. They also have many change orders, additional cost, adversarial confrontations and a construction schedule that grows.

BARRIERS TO REDUCING DESIGN ERRORS

Owner responses:

- Profit motive. Personnel turnover.
- Usually time, by the time that a project is design released, we are at the end of the fiscal year. We are forced to accept a package that is less than coordinated.
- The Federal bureaucracy is just to big too fight through.
- No time is what you will hear. In reality with proper planning we could devote more time to all aspects of design including the quality issue.
- Cost/time pressures and a lack of discipline. A&Es are rarely held accountable for the true cost of their errors.
- Usually the drive to produce a project faster. The client wants the job completed tomorrow and does not give the A&E adequate time to do a really good job. "Done is better than good."
- Owner should design and contract.

Designer responses:

- Time and expense.
- "Partnering" is a valued tool towards a successful project; it should be mandatory with most all projects. Also, contractor "alternatives" to design documents related to means/methods of construction.
- Time allowed on a project vs. the budget.
- Money for design.
- In the current climate, it's the speed of the process as dictated by owners and the business level which stretches personnel resources that inhibits better results in the design and drawing process.
- A major factor is adversarial contracts that attempt to push liability from one party to another. Second major factor is time and fee pressure.

Contractor responses:

- Time, compensation and liability.
- Current workloads have design professionals spread thin.
- Time and money pressures.

Table 7-1. Barriers to Reducing Design Errors.

VIII. STEPS TAKEN TO REDUCE DESIGNER ERRORS

If designers are given adequate time to complete design documents, do they need to develop Quality Control/Quality Assurance plans? This is an interesting question. From the survey firms have introduced different steps in order to reduce the number of design errors. The responses are provided in Table 8-1. Within the realm of Total Quality Management concepts, firms have developed Quality Control plans as a check and balance system to reduce the number of design errors and reduce contractor rework. The reduction in errors and rework is possible through better coordination within the different disciplines. These plans establish criteria to review all the documents within the package. All the coordination and reviewing can only be totally served through effective communication.

Owners' responses were fundamentally driven toward the designer obtaining and adhering to a Quality Control plan. A Quality Control plan would consist of various reviews and the incorporation of more field investigations.

One owner response requested a return to actively pursuing A&E liability towards design errors. This is necessary for the design firms that do not accept the responsibility, governed by law, to ensure documents that are complete and useable and virtually free of error.

Designers indicated that they have taken steps to develop regular coordination meetings between engineers and contractors enhancing the communication level. They also developed an out-of-house design review with the contractor to discuss not only the current phase of the construction but also the next phase(s). This forward thinking

allows the ***team*** to foresee any problems that might develop while there is time to correct them without hindering the construction schedule.

Contractors are taking greater steps to review the drawings using system checks. Although still operating under a time limitation, the contractor is devoting more assets to the up front review. After the bid award, the contractor continues to review the drawings early in order to reduce fewer project interruptions.

STEPS TAKEN TO REDUCE DESIGN ERRORS

Owner response

- ❖ More review phases of documents. Better guidelines for design professionals.
- ❖ Require the A&E to submit his Design Quality Assurance plan for each project. The plan identifies responsibilities of the design team. The plan is tied to the design schedule so that the owner's Project Leader can visit the A&Es' office at critical points to make spot checks and assure that the A&E is performing in accordance with the Quality Assurance plan. The owner has his own plan.
- ❖ Our local system has recently showed renewed interest in pursuing A&E liability. Assuming that interest continues, the A&E community will respond with better quality designs to avoid paying contractor repair costs which include large sums of money for delay costs.
- ❖ We talk a lot about it but very little is actually done. We have tried to emphasize the A&E firm's internal Quality Control program as part of the selection process.
- ❖ We emphasize the submittal of the A&E's Design Quality Control plan where the A&E spells out step by step how they will coordinate their work and disciplines.
- ❖ Going to design/build contracts to get us out of the middle between A&E and contractor.

Designer response

- ❖ Regular coordination meetings. Coordination of CAD drawings between disciplines. Communication between disciplines.
- ❖ Design review sessions in-house and with contractor out-of-house document review.
- ❖ Implement QA/QC procedures early in a project and check all products before they go.
- ❖ Design review and quality control review.
- ❖ Clarify program elements to consultants; receive sign off on program elements from owner.
- ❖ Principal review, employee education, awareness of liability issues in our contracts.

Contractor response

- ❖ Continuous value engineering by Project Managers.
- ❖ Redi-check reviews are performed during the design process. These are used to check for errors and omissions.
- ❖ Give designers more money and time.

Table 8-1. Steps Taken to Reduce Design Errors.

IX. RECOMMENDATIONS TO REDUCE DESIGN ERRORS

The survey produced several feasible recommendations, provided in Table 9-1, to improve the quality of design and reduce the design errors to include omissions and ambiguities. First and foremost is resolving the scope definition before starting the project construction. It should be a joint effort between the owner and designer while including the contractor in on the major concepts. Baring any contractual agreement, there should be an open line of communication between all the principle parties. Included in that is the understanding of managerial skills and what constitutes a design error that will effect the cost and schedule of the project. The greatest measure of success is the sharing of information. Designers should take full control of the review process, both in-house and out-of-house. Adequate time should be given to complete the design documents including reviews, field investigations and greater involvement in the inspection process. Provide the designer and contractor an avenue to discuss problems and resolve them without intervention of the owner. It is most surreally time to properly compensate the designer in both time and monies. The cost of doing business is growing every year and the percentage for payment has remained the same. CAD has not decreased the expenditures but raised them. In promoting the design factor of quality over time and cost all parties will create a win-win scenario and ensure the highest quality of construction.

RECOMMENDATIONS TO REDUCE DESIGN ERRORS

Owner response

- ❖ Raise design fees and hire more competent A&Es. Don't start construction until documents are ready.
- ❖ Emphasize the importance of proper field investigation. Give extra time and money to perform field investigation. Request the submittal of the A&E's quality control set of documents, to prove they did a quality check.
- ❖ Use CAD software that identifies cross discipline conflicts. A&Es must perform detailed drawing reviews using a very structured approach. Owners must identify and communicate their requirements early in the process.
- ❖ Make the A&E accountable, spend less time reviewing A&Es work and give A&Es more time to design.
- ❖ Better acquisition planning and having the latitude at the local level to vary from the Brooks Act spending limitations.
- ❖ Assure that the A&E has a good, documented Quality Control plan and that it is tailored for each project. Also, assure that the owner has a Quality Assurance plan that is followed. Also, if the A&E has not performed adequate Quality Control do not be afraid to send that package back for design.
- ❖ Pay better fees. Do a better job of A&E selection. Reward good firms with additional work.

Designer response

- ❖ Develop design/construction document review checklists for all disciplines and review prior to document issue.
- ❖ Ensure each discipline has the time and work force to produce the project. Require periodic coordination meetings for all disciplines.
- ❖ Try to confirm that your client's expectations meet what the designer has contracted to deliver. Proactively educate staff.
- ❖ Establish QA/QC procedures that are used on every project.
- ❖ Review by senior architect of work, budgeting sufficient time and fee to do the job, caution in making design changes, writing good contracts.
- ❖ Document, document and document. Decisions and direction by owner especially with regard to value engineering items.

Contractor response

- ❖ Communicate goals clearly and concisely.
- ❖ Consult with contractors for practical construction techniques.
- ❖ Give designers more money and time.

Table 9-1. Recommendations to Reduce Design Errors.

CONCLUSION

There are many initiatives being conducted to control the growth of cost and schedule within the construction industry. The major issue is the "accuracy of the drawings," or the number of design errors, omissions and ambiguities within the plans and specifications that affect the quality of the facility. So much emphasis is placed on the issue of time and cost that quality takes a back seat. The quality of the project depends on the conformance of the objectives and requirements. This is achieved if the owner establishes and communicates the scope of work to the designer who then clearly stated these requirements in the contract documents. An informative quality management technique will provide an agreement to procedures and definitions among the principle parties for the project. It is understood that the more time established in the design and bidding phase will lead to a quality product that will finish within schedule and within budget. This will minimize litigation and confrontation. The design team should continually educate themselves with the construction techniques performed by the contractor and incorporate that knowledge into the details of the project. By integrating quality as the main focus of the design, the design team will be required to deal with communication between the principle parties, coordination of the other disciplines and adequately review the plans and specifications before issue.

Appendix A

Glossary of Terms

This glossary represents definitions adopted by the Construction Industry Institute in April 1987 and October 1987.

Change: A directed action altering the currently established requirements. Changes may encompass Design, Fabrication, Construction, etc. and materially affect the approved requirements, the basis of design, the existing scope of the contract plans and specifications, or operating capability of the facility.

Constructability: The best integration of construction knowledge and experience in planning, engineering, procurement and field operations to achieve overall project objectives.

Cost of Quality: The cost associated with quality management activities (prevention and appraisal) plus the cost associated with deviations.

Design Effectiveness: An all encompassing term to measure the results of the design effort including input variables and design execution against the specified expectations of the owner including such criteria as cost, schedule, quality and others explicit of implicit in the project objectives.

Deviation: A departure from established requirements. A deviation may be classified as an imperfection, non-conformance, or defect based on its severity.

Error: Any item or activity in a system that is performed incorrectly resulting in a deviation, e.g., design error, fabrication error, construction error, etc. An error requires an evaluation to determine what corrective action is necessary.

Imperfection: A deviation which does not affect the use or performance of the product, process or service. In practice, imperfections are deviations that are accepted as-is.

Non-conformance: A deviation that occurs with a severity sufficient to consider rejection of the product, process or service. In some situations the product, process or service may be accepted as-is: in other situations it will require corrective action.

Omission: Any part of a system, including design, construction and fabrication, that has been left out resulting in a deviation. An omission requires an evaluation to determine what corrective action is necessary.

Project: All those elements associated with a facility from initial concept to final disposition.

Quality: Conformance to established requirements. (Not a degree of goodness)

Quality Assurance: All those planned or systematic actions necessary to provide adequate confidence that a product, process or service will conform to established requirements.

Quality Control: Inspection, test, evaluation or other necessary action to verify that a product, process or service conforms to established requirements.

Requirement: A contractually established characteristic of a product, process or service. A characteristic is a physical of chemical property, a dimension, a temperature, a pressure, or any other specification used to define the nature of a product, process or service.

Scope: Work description and intended operation of the facility. It sets the basis for project plans, budgets, schedules and reference points for later evaluation of results and generally includes:

- Type of project and description of facility
- Basic data availability and data available form previous projects
- Primary and secondary objectives and priorities including costs, schedules, capacity and product quality
- Description of "state-of-the-art" for new process equipment
- References on process fluids, materials of construction and type of instrumentation
- Automated system requirements and software development
- Description of any need to alter normal construction sequence
- Alternates being considered and potential impact on scope

Appendix B

Master Report Survey

The University of Florida Civil Engineering Department is conducting a survey on the quality of construction work as related to design errors. There are research initiatives being conducted to reduce the number of design errors and rework on construction projects. Our intention is to initiate a finding of acceptable avenues of confronting ways to reduce design errors prior to construction.

My firm is: ☐ Owner
☐ Designer
☐ Contractor
☐ Educator

1. Define Design Errors.

____
____
____

2. Who should pay for design errors?

☐ Owner ☐ Designer ☐ Contractor

3. Of 100% of the project changes, what percentage can be attributed to the following?

_____ Rework (Contractor Errors) _____Design Errors (Designer) _____Change of Scope (Owner) _____ Other

4. From your experience, what percentage of all contract changes were caused by design errors?

0% ——————— 50% ——————— 100%

5. List in order the factors that control design and construction.

_____ Speed _____ Quality _____ Other
_____ Quantity _____ Safety

6. Has the implementation of CAD lessened the number of design errors?

☐ Yes ☐ No _____ % change

7. Has CAD improved production?
☐ Not at all ☐ Somewhat ☐ Greatly

8. What steps has your firm taken to reduce design errors?

____

____

____

9. What do you feel is the major contributing factor to design errors?

____

____

____

10. What steps can you recommend to reduce the number of design errors?

____

____

____

11. What is preventing the parties to a project form taking greater steps to reduce design errors?

____

____

____

Thank you for your assistance in completing this survey. Please feel free to include any other comments you may have on this issue. We request that the responses be returned no later than July 3rd. Please return your completed copy to: Dr. C.A. Glagloa, University of Florida, Gainesville, FL 32611-6850. You may also e-mail the completed survey to cglag@ce.ufl.edu or seabees3@aol.com, or fax to (352) 392-3394.

Appendix C

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